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By
Abel Wolman
Arthur E. Gorman

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WASTE MATERIALS IN THE UNITED STATES ATOMIC ENERGY PROGRAM*

By Abel Wolman and Arthur E. Gorman

Dr. Alan Gregg, the Chairman of the Atomic Energy Commission Advisory Committee on Biology and Medicine, gives the key to virtually all the problems of disposal of the waste materials in the Atomic Energy Commission program. In his foreword in the Sixth Semi-Annual Report of the Atomic Energy Commission of July 1949, he states, "The Commission is charged by law with the exclusive control of materials, equipment, and processes which are unique, constantly dangerous, and certainly not yet sufficiently understood. To this task is added the difficult circumstance, foreign to most other scientific enterprise, of secrecy...Virtually a second world for study and exploration comes thus into being as a result of profoundly understanding the laws that govern the phenomena of the world about us--the first world we studied and explored."[1]

The industry for which the Commission is now responsible has many parallels, however, in the more orthodox industries with which most people are familiar. It takes commonly-known raw materials and by new processes of refinement and conversion it produces old and new materials which have many useful as well as destructive characteristics. The uniqueness of the industry stems, however, as Dr. Gregg has pointed out, from the exclusive control which the Commission exercises, from the secrecy which surrounds many of the processes and decisions and from the imperfectly understood features of some of the processes and of the effects of their resulting wastes.

The history of most industrial operations discloses perhaps too many instances of the production of wastes with ill effects on people, land, or water. In these more familiar trades, however, effects were visible, frequently measureable and invariably under some form of continuing public and often official scrutiny. Even in such a situation, the literature is replete with errors of judgment, of undue exposures of man, animal, and plant life, of struggles toward corrective measures and of continual checking and rechecking by disinterested observers. In the atomic energy program, secrecy of purpose makes the waste disposal problem far more difficult of evaluation and of correction.

The industry is concerned with high energy radiation, having its origin in the core or the nucleus of the atom. The common source, for

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the moment, of most of the processes is the uranium ore, analogous in many respects to the raw materials or ores which might be processed initially in such an industry as steel making. Energy is released from the refined uranium by splitting the atom, with consequent production of high energy radiation. As far as is known all high energy radiation has approximately the same kind of effect on living cells and living tissues. Some forms of radiation may cause greater amounts of damage, but the general type of injury is the same.

Unfortunately, the exact mechanism by which radiation harms living molecules, cells, and tissues is not sufficiently understood, although in the last 20 years radiologists have codified the rule of thumb methods for working with x rays and radium. As would be expected, many former views are now being revised under the impact of new knowledge and the margins of safety for protecting man against radiation have been regularly widened. As a matter of fact, within a period of 20 years the level of radiation formerly allowed has been cut virtually in half. Many activities are under way seeking to provide data upon which to evaluate the effects of different radiations, and consequently to establish approximate standards and rules, "but, here again, the investigators are deeply aware of a lack of basic, fundamental knowledge of the mechanism of radiation effects."[1,2,3]

Problems in radioactive waste disposal arise in approximately the same manner as would be the case in many analogous industries. In the operation of a chain-reacting pile, for the production of plutonium, for the production of radioisotopes, for the development of power, or for experimental purposes, the necessity ultimately arises of separating, chemically, various radioisotopes from the mixture of partially depleted uranium and its products.[4] Separation processes involve the use of large amounts of liquid carrying considerable quantities of radioisotopes in solution. In similar fashion, considerable quantities of radioactive gases or of air-borne radioactive materials result. The pile coolant itself, whether air, water, or other material is a source of possible gaseous, solid, and liquid contamination. The amount and nature, and the effect of such materials upon the air, receiving bodies of water and plants and animals, are important considerations for determination. The water supply, sewage, and refuse of working or other areas at times are also affected. Essentially, the question is a simple one. Are such materials harmful to man, to plant, or to lower animal life and in what concentrations may they be permitted to be discharged with safety into the atmosphere, into the water or on to the land? Unfortunately, most of these materials cannot be neutralized by any known practical method. They either must "outline" their hazardous effects or they must be permanently shielded against the outside living world. In addition, medical research has not discovered any treatment which for the moment will neutralize the tissue damage if such radioactive materials are fixed in the body tissues.

The engineer and the medical officer confronted with these problems, for which no firm guides are available as precedents, must necessarily adopt a conservative attitude toward the control methods now practiced or being evolved. Here policy issues arise, but the benefit of doubt must be given to the public. Hence the establishment of permissible limits of radioactivity in air, water, and food are expected to provide a high factor

of safety, until biological research, firmly supported by epidemiological experience, establishes strong and positive bases for reducing such factors of safety.

In evaluating the hazards it is important to re-emphasize the fact that very small concentrations of many of the radioisotopes produce tolerance dosages. Furthermore, as Forrest Western has pointed out[4] a distinction must be made between tolerance concentrations and operating practices. In the latter cases, he, as well as most investigators, insist that liberal safety factors are essential in the present state of knowledge. He points out in addition, as will be discussed later herein, that when such materials are drained into a sewer, stream, or bay, it cannot be assumed that such radioactive wastes will necessarily remain in the dilution originally calculated for such control purposes. The greatest amount of care must be exercised in continued checking in order to be assured that nature's capacity for concentrating various chemical elements is not coming into play and vitiating the assumed dilution results. This is particularly true if it is remembered that radiation effects may be of long duration, even following short wartime uses.

The monitoring of discharged air, water, and solids, therefore, becomes one of major continuing administrative functions of the Commission. Without such detailed monitoring radioactive contents in the surrounding world may become excessive. Emphasis upon this phase of administrative housekeeping cannot be too great. That such monitoring shall remain the exclusive monopoly of the Commission, without a rising parallel testing by federal, state, and municipal health authorities is highly questionable.

The establishment of the permissible limits of radioactivity to which man may be safely exposed, either for short intervals of time or for a lifetime, is admittedly a difficult task in the present state of knowledge. Extrapolation from findings on lower animals to the impacts upon man are likewise unsatisfactory. Experimentation upon human beings is of course difficult, particularly where long-range effects are of significant importance. Most experts indicate that evidence regarding chronic exposure to radioactivity is unfortunately very meager. In the discussions of permissible limits, particularly with reference to drinking water, some workers have contended that large factors of safety should not be employed on the reasoning that the results would lead to radiation levels which are many times smaller than some of the natural radioactive waters now being drunk at health spas. Opponents of this view properly insist that large urban populations have never been exposed to drinking such radioactive waters for a life span and it is indeed unknown how many cases of cancer such a practice would have produced. Epidemiological studies of populations exposed to high natural radioactive health waters have not been satisfactorily explored. The values of radioactivity inherent in these waters, therefore, should not be summoned up as reasonable basis for comparison with daily ingestion by large populations over a lifetime.

At the moment, most authorities apparently feel that a differential permissible limit should be established for plant employees considerably in excess of that which would be acceptable for off-site large populations,

largely because such employees can be kept under much closer check than would be the case for the general public. It is also clear that in war permissible limits undoubtedly would be moved upward on the bases of general increased risks to life.

Permissible dosages in air and in drinking water are shown in Table 1. Although Table 1 summarizes some of the best present estimates, it must be admitted that the permissible limits as stated in many instances do not rest on very solid scientific grounds. Until something better is available, however, the limits do appear to provide high factors of safety and certainly may serve as guides for the determination of practices in the control of discharge of nuclear fission wastes.

ADMINISTRATIVE PROBLEMS

This unsatisfactory situation as to permissible limits has counterparts in many other industries. The health officer, the toxicologist, and the food chemist are almost always confronted with this same dilemma, particularly where regulatory measures are under various more familiar elements. One of the recent authorities in this field has aptly reflected the dilemma with which we are confronted in the atomic energy industry by pointing out that in the food industry "agreement between what is clearly toxic and what is undoubtedly harmless is not likely to be reached without far more complete knowledge of human physiology than we possess at present." It is further pertinent to our discussion here today to continue the quotation from Monier-Williams that "meanwhile, any reference must be on the side of the consumer."[5]

The administrative officer, of course, is always caught between the Scylla, of avoiding impeding progress in the industry, and the Charybdis, of protecting the general population against the hazards of a new industry.

In this connection it is worth recalling that at least part of the medical profession was confident that lithium chloride could be used to supplant sodium chloride for patients requiring a low sodium content. Not a single voice was raised against such use until a few deaths were recorded within the last 12 months. The incident serves to recall that lithium was at one time regarded as an important and safe ingredient of certain so-called health waters.

Before the details of the nature and the sources of wastes are discussed, we should revert very briefly to the important problem of administrative control over atomic energy operations in the United States. The unique character of this most important industry has already been mentioned. By Congressional Act the Atomic Energy Commission has virtually sole power over this important development. In this respect it is unlike any other industry with which the public has hitherto been confronted. Normally the activities of an industry, which potentially may have some public health influence upon the surrounding population, has the continued scrutiny of official public health agencies, on federal, state, and local levels.

In the case of nuclear fission operations, however, a publicly owned and operated industry has been assigned by Congress the task of developing complex processes, of establishing standards of permissible limits for

Table 1*--Permissible Concentration of Radioisotopes

Isotope	Permissible conc. in the tissue (uc/g)	Maximum oral adsorption (fraction)	Maximum in critical organ (fraction in organ)		Permissible conc. in inhaled air for insoluble compounds (8 hr day) (uc/cc)	Permissible conc. in inhaled air for soluble compounds (8 hr day) (uc/cc)	Permissible conc. in water (uc/cc)	Permissible conc. in urine (uc/cc)	Effective half-life (days)
Ra	2.8×10^{-6}	0.35	Bone	0.99	2.0×10^{-13}	1.3×10^{-13}	1.1×10^{-10}	5.5×10^{-10}	16000
Processed U	9.2×10^{-6}	0.0005	Kidney	0.45	3.5×10^{-10}	1.7×10^{-10}	7.6×10^{-4}	2.6×10^{-7}	5
and products			Lungs		2.1×10^{-11}			3.5×10^{-8}	120
			Bone	0.20	1.5×10^{-9}	7.4×10^{-10}	3.4×10^{-3}	5.0×10^{-6}	60
Pu^{239}	7.9×10^{-6}	0.007	Bone	0.75	2.8×10^{-11}	1.4×10^{-11}	4.8×10^{-6}	3.5×10^{-8}	730
P^{32}	1.2×10^{-3}	0.30	Bone	0.48	2.3×10^{-7}	1.4×10^{-7}	1.4×10^{-3}	2.3×10^{-5}	13.2
			Muscle	0.25	1.8×10^{-6}	1.1×10^{-6}	1.1×10^{-2}	4.6×10^{-5}	13.8
I^{131}	3.7×10^{-3}	1.00	Thyroid	0.20	4.4×10^{-9}	3.3×10^{-9}	1.5×10^{-5}	1.1×10^{-6}	6.32
S^{35}	1.5×10^{-2}	0.56	Bone	0.34	1.3×10^{-6}	8.8×10^{-7}	5.6×10^{-3}	9.9×10^{-4}	31.3
			Liver	0.25	6.5×10^{-6}	4.4×10^{-6}	2.8×10^{-2}	5.6×10^{-3}	2.05
C^{14}	1.5×10^{-2}	0.30	Total Body	1.0	1.0×10^{-3}	6.4×10^{-4}	6.3	2.8	0.174
K^{42}	5.2×10^{-4}	0.90	Muscle	0.67	6.6×10^{-6}	3.4×10^{-6}	1.7×10^{-2}	8.4×10^{-4}	0.490
Na^{24}	3.0×10^{-4}	0.58	Total Body	1.0	4.5×10^{-6}	3.1×10^{-6}	1.9×10^{-2}	4.0×10^{-4}	0.604
Sr^{89}	1.5×10^{-3}	.05-0.60	Bone	0.70	7.6×10^{-8}	4.3×10^{-8}	7.4×10^{-4}	2.4×10^{-5}	41.9
Sr^{90} -Y^{90}	7.2×10^{-4}	.05-0.60	Bone	0.70	7.8×10^{-9}	4.5×10^{-9}	7.8×10^{-5}	1.2×10^{-5}	196
Ca^{45}	9.3×10^{-3}	0.90	Bone	0.90	5.3×10^{-8}	3.9×10^{-8}	1.9×10^{-4}	2.6×10^{-5}	134

*Adapted from a table prepared by Dr. K. Z. Morgan, Health Physics Division, ORNL. To be published by the National Research Council in the Handbook of Nuclear Instruments and Techniques. (Reference: "Investigations on Radioactive Waste Disposal in Relation to Water and Sewage Treatment" O. R. Placak & R. J. Morton. Presented at the 21st Annual Meeting of the Kentucky-Tennessee Section of the American Water Works Association and the 3rd Annual Meeting of the Kentucky-Tennessee Industrial Wastes and Sewage Works Association 10-31 and 11-1-49.)

human exposure, of administering disposal programs to comply with such limits, and of reviewing the successes or failures of each of these steps as the industry progresses. The unique character of this situation with reference to industrial wastes need not be labored. The normal processes of supervision and regulation generally available through federal, state, and local health departments and health officers are missing and their initiation is handicapped by security policies. These official agencies, however, undoubtedly have something necessary and valuable to provide. Although the Atomic Energy Commission has extended materially its areas of interagency participation in recent years, more complete joint discussions have unquestionably been retarded by the difficulties of security measures and the "strangeness" of the industry.

The relationship between nuclear fission operating control and official health department review in this country is quite different from that which prevails in England. In the latter country, as in the United States, sole responsibility for all atomic energy operations rests with the Ministry of Supply. But from the beginning of its operations, consultation with the Ministry of Health and other official agencies responsible for public water supplies and other amenities affecting the public, have been continuous and thorough. Monitoring of the important sources of water supply which may be affected by atomic energy operations is not only in the hands of the Ministry of Supply, but is paralleled in detail by the forces of the Ministry of Health and of the Conservancy Districts affected. Such acceptance of joint responsibility has not yet been consummated in this country. As operations in the field of atomic energy are continually expanding, and are already larger perhaps than those of any other industry in the United States, the establishment of such official relationships is desirable, not only in the control of wastes, but in many other industrial operations of potential significance to the general public.

Under the terms of the British Radioactive Substances Act of 1948, the Minister of Supply was given the right to form a committee to advise him and the Ministry of Health on matters concerning radiation protection. Sir Henry Dale has since been appointed chairman of the Radioactive Substances Advisory Committee on which the Ministers of Health of Scotland and Northern Ireland also sit.

In the meantime, the International Labour Office in Geneva has proposed in the fall of 1949, a tentative model code of safety regulations for use in industrial establishments for the guidance of governments and industry. Some 18 printed pages of this code are devoted to the subject of "Dangerous Radiations." Whether this composite of existing and proposed regulations is appropriate in any degree to the needs and practices in this country the present authors do not know. That some official authoritative criteria are needed, is recognized and steps in some areas are already being taken to work toward this goal.

GUIDING PRINCIPLES IN DISPOSAL

The detailed discussions of wastes which follow are directed primarily to the problems inherent in peacetime utilization of nuclear energy, as distinct from radiation dangers in an atomic war.[6] In the peacetime operations, the following dicta appear reasonable in the present state of the art:

1. Permissible doses of radiation may be set forth authoritatively, but are still subject to experimental and long-range check and development.

2. Protective measures of practical and feasible character are available, but their limitations are still unduly restrictive and expensive and require further study.

3. The problem of the disposal of radioactive wastes is still one of the most important confronting the industry, even though great progress has been made in identifying the issues and in improving the results of waste treatment.

4. Wastes cannot be described as "disposed of" if their half-lives are long and if they are simply transferred from one part of the globe to another.

5. Too little is now known about the biological effects in man to risk a large scale pollution which would be difficult or impossible to eliminate.[7]

6. The Commission would like to get as near zero output of radioactivity as it can obtain.[8] Its activities are uniformly directed toward that aim.

TYPES AND SOURCES OF WASTES

The Problem

The atomic energy industry, like any other industry, has its waste products which must be disposed of properly both for the protection of its workers and the public. On one score--radioactivity--its problems of waste disposal are different and more complicated than those of most other industries. On another--toxicity--its problems are both similar and different from those experienced by other industries.

The principal raw material used in the industry is uranium-bearing ore. Many of the products sought result from nuclear chain reactions in prepared uranium fuel material. Many of the wastes from the various intermediate operations are radioactive, usually at progressively higher levels as processing operations are carried out. An important feature of radioactive waste products is that they emit radiations for varying periods, ranging from seconds to thousands of years. At the place of storage or the point of discharge, however, or even at some distance from either, none of the characteristics usually associated with an objectionable waste such as color and odor may be in evidence. None of the tests normally indicative of a contaminant in air, water, or food and commonly applied to other industrial wastes will reveal the presence of radioactivity. Differences in properties and their significance and differences in methods of detection of radioactive materials make the problems related to the disposal of such wastes unique.

In addition to radioactive materials, the industry uses certain chemicals and chemical products which have toxic properties or acquire them in processing. Waste products from these operations must also be disposed of with great care. Among these items are fluorides, lead, beryllium, cyanides, and spent acids. In meeting such problems the experience of other

industries can be drawn on, although in some cases the products involved are from rare metals whose properties in relation to health have not been too well understood.

In the research branch of the industry, as contrasted with the production branch, there are a wide variety of waste products ranging from radioactive and chemically complicated wash waters from decontamination laundries to the carcasses of animals used for biological experiments. Many of these wastes present special and perplexing problems in disposal.

Low-Level Radioactive Wastes

In mining, transporting, and storing raw uranium ores some wastes as losses will occur. Although their level of radioactivity is low, large concentrations of such materials may give off sufficient rays to damage human tissue if intimate exposure to them were to be too prolonged. Radon, a decay product from the radium present may also be hazardous especially when inhaled. Therefore, such wastes are under strict control. Losses are reduced to the lowest possible amount. As in any mining industry care must be taken in all operations to protect workers from exposure to the dusts and from prolonged intimate contact with the ore. With good industrial housekeeping, proper handling, and use of dust control equipment and ventilating facilities, hazards associated with these products and the wastes can be kept at a safe level.

In the drying, crushing, grinding, sieving, packaging, and shipping of uranium ore for subsequent chemical processing and in clean-up operations at such plants, waste products in the form of radioactive dusts and washings will occur. This material can be kept under control by the installation of such facilities as cyclones, electrostatic precipitators, bag and diaphragm filters, scrubbers, and settling facilities.

The chemical processing of the prepared uranium ore for the production of its brown oxide (UO_2), its green salt (UF_4), or the gaseous UF_6 presents the ordinary problems of chemical industries which use toxic solvents and extracting solutions and complicated reactors. Mists and fumes must be controlled and contaminants removed by scrubbing, filtering, or other suitable means to prevent atmospheric contamination which could be hazardous to workers. Because of the value of the materials being processed systems are usually closed. The residues from the processing of most uranium compounds have low-level, long-lived radioactivity. Storage or disposal areas are carefully selected to prevent leaching from affecting surface or ground water supplies used for domestic, industrial, or agricultural purposes.

Refined uranium metal, one of the end products of the chemical processing , is fabricated to proper shape for reactor fuel. This requires rolling, extruding, machining, and other metallurgical treatments. In these operations fumes of uranium oxide may be given off as atmospheric contaminants. Therefore, rooms are ventilated. Exhaust gases are cleaned by scrubbing or filtration or both. Water used in the cooling or clean-up operations in such plants contains uranium dusts and chips. They are reclaimable by settling in basins with or without chemical precipitation or by filtration, and, therefore, need not contaminate any waterway or sewer system.

High-Level Radioactive Wastes

The irradiated products of reactors contain high-level radioactivity. These wastes have been called the ashes of the nuclear furnace but they cannot be disposed of as ordinary ashes. The most highly radioactive wastes are those remaining after the product desired, such as plutonium, is removed from the irradiated fuel by chemical separations processes. These wastes contain various fission products and inadequately irradiated uranium. They are highly dangerous because of their radioactivity. They are extremely valuable because of the recoverable uranium and other important materials they contain. Currently, these highly dangerous wastes are stored, but ways and means of recovering the valuable products in them are subject to much investigation. After certain cycles of decontamination have been completed the level of radioactive contamination drops very materially. As in the case of other wastes, a point is finally reached at which a decision must be made between the economics of further decontamination and the realities as to public health risks involved in release of these wastes to nature. Under present circumstances prudence dictates a conservative course of action in favor of protection of public health.

The separations processes start with dissolving of the metallic container in which the fuel was sealed for use in the pile. Then follow a series of chemical treatments designed to separate the plutonium or other product desired. These operations are carried out in specially designed chemical treatment facilities set up in cells heavily shielded. Manipulation of operating and control equipment within the cells is by remote control. The cells and chemical treatment facilities are vented while in use. Periodically, openings in normally closed systems are made for repairs or for special charging and decontamination operations. Control monitoring is essential for protection of workers.

Waste off-gases from dissolver operations include nitrogen oxides and radioactive fission products such as iodine, xenon, and krypton. Off-gases are both corrosive and radioactive. For this reason, special consideration is given to the selection of materials used in facilities for their removal, treatment, and disposal. Because of cumulative radioactivity high rate of obsolescence of equipment and difficulty in carrying out routine maintenance are common. This makes the task of handling these gases especially troublesome and expensive. Buildings in which dissolver operations are carried out require special ventilation to safeguard workers.

Release of off-gases and cell and building ventilating air to the atmosphere even through high stacks is controlled carefully in order to protect plant and area operators and to prevent contamination of the air and the ground when the airborne particles settle out. Under unfavorable atmospheric conditions such as looping, inversion or low-wind velocity, dissolving operations could result in serious contamination in the area of the stacks or vents from which gaseous effluents are discharged were controls not in effect.

In water-cooled reactors of the flow-through type such as those at the Hanford Works on the Columbia River, one of the important wastes is the cooling water. This water becomes irradiated by the neutrons which

are emitted in the fission processes. It is because of this induced radioactivity that the water must be pretreated so that it contains no objectionable dissolved or suspended matter. This matter, when irradiated, would carry long-lived radioactivity back to the river where the cooling water is discharged after a period of retention. The retention period is sufficiently long to allow induced radioactivity in the water to deteriorate to levels considered to be safe. Irradiated fuel as ejected from the reactors is discharged into temporary receiving basins in which water is used as a shield. Later, after transfer from the reactor basins, the fuel is stored elsewhere in holding basins through which water flows continuously. The waste water in these basins may contain some radioactivity depending on the condition of the fuel element after discharge from the reactor.

In an air-cooled reactor such as that at Brookhaven the principal atmospheric contaminant is radioactive argon which has a half-life of 110 min. As in the case of water for water-cooled reactors, the cooling air is cleansed and freed of particulate matter which, on exposure to neutrons in the reactor, would become radioactive.

Other gaseous contaminants are the discharges from ventilation hoods in process or research laboratories. Unless decontaminated or discharged high enough over the roofs of buildings to provide for effective dilution in the atmosphere, such discharges could contaminate roofs and thereby create hazards for maintenance workers. Under unfavorable meteorological conditions they could, if they were not subject to controls, build up considerable contamination of the atmosphere in the vicinity of their discharge points.

Laboratory Wastes

In laboratories, whether of the production or research type, a wide variety of wastes may result depending on the nature of the work carried out. Usually product containing high levels of radiation is worked in separate units of the laboratory. Here remote control facilities are used, monitoring is strict and a high degree of accountability is enforced. The amount of waste in product is exceedingly small. Equipment, instruments, and glassware may in time become contaminated by radioactivity to such a degree that normal decontamination methods are inadequate. Then they must be taken out of service and be allocated to waste storage. In research laboratories--chemical, biological, metallurgical, or general--where radioactive materials of intermediate or low-levels of activity are handled, the waste problem exists and precautions in monitoring and disposal are essential.

In the laundering of special clothing worn in the laboratories a considerable volume of low-level waste results which is difficult to treat because of the special detergents and decontaminants used. Such wastes often contain citrates and phosphates and their treatment from the standpoint of disposal presents a difficult problem. In the various laboratory operations waste of such items as paper, gloves, glassware, and biologic specimens containing various levels of radioactivity accumulate in considerable amounts. They must be kept in separate containers which are

monitored regularly. Combustible wastes cannot be disposed of by burning, as normal laboratory waste of this kind would be gotten rid of, unless provision is made to decontaminate the gases of combustion.

If for one reason or another, it is desired to wreck a building which has become contaminated by long-lived radioactive material, demolition work must be carried out under the constant supervision of radiomonitors. Working time is limited by the amount of exposure received. Added protection can be given to workers by covering the contaminated surfaces by a suitable paint or other material. Material removed in the wrecking operations, if radioactive, cannot be disposed of through normal salvage channels. Possible methods of disposal include storage, burial, or burning, as will be discussed elsewhere.

Toxic Wastes

The use of large amounts of acid and alkali solvents and chemical extraction solutions present a problem of health safety in use and control. These systems are usually closed and the chemicals are reclaimed, but ultimately spent liquors and residues must be disposed of. Very substantial amounts of fluorine are used in chemical processing and the disposal of wastes containing compounds of this element requires careful consideration. Among the many rare metals which have a usefulness in this new industry beryllium presents special problems. Hazards related to the use of this element is fluorescent lamps is familiar to most industrial hygienists. Cases of beryllium poisoning among employees at plants using this material and among residents in the vicinity of one plant in particular have given emphasis to the importance of beryllium. In metallurgy the use of cyanides and other toxic chemicals present waste disposal problems similar to those of other industries.

PRESENT PRACTICES IN HANDLING RADIOACTIVE WASTES

In a review of present practice in the atomic energy industry in handling and disposing of wastes it is helpful to consider them in the solid, liquid, and gaseous states. Currently the problems of treatment and disposal are more acute in relation to liquid and gaseous wastes. Ultimately, however, the problems of disposal of solid wastes having long radioactive half-lives may prove to be the most difficult to resolve. This is because the trend is toward removal of radioactive decontaminants from gases and liquids and reducing their volume to a solid or near solid state for permanent disposal; and also because certain solid wastes such as construction materials and chemical equipment are voluminous.

Solid Wastes

Wastes such as dusts, chips, and particles of product collected in quantities by dust removal and reclamation facilities usually are returned to supply or are reconditioned for use. In ore grinding and sieving and at chemical and metallurgical plants, cyclones, bag filters, and electrostatic precipitators are used. The behavior of radioactive particulate

matter in dust removal facilities in not necessarily the same as nonradioactive material. Furthermore, in design of such equipment ease of access for maintenance and repair needs to be given special consideration because exposure of workmen to radioactive dusts must be for limited periods. The special condition of cumulative radioactive contamination is being studied further. Research work along these lines has been recommended.

Residual sludges from the chemical processing of uranium ores at contract chemical plants which usually have low levels of radioactivity are stored temporarily at the plants in steel drums. At frequent intervals, they are shipped in special cars to a central storage base under control of the Commission. These wastes are held in concrete tanks which prevent leaching into the ground or spillage to affect surface water sources. They have potential reclamation value and are sampled and monitored regularly.

At major operating areas such as Hanford, Oak Ridge, and Los Alamos isolated burial grounds have been designated for the disposal of solid wastes which are radioactive. These wastes are collected locally and may also be received by shipment from various laboratory and operating areas. Such wastes consist of glassware, gloves, contaminated boxes, equipment, pipes, fittings, and miscellaneous materials. The earth cover over these burial pits is usually 12 ft and the surface is monitored regularly. The area is fenced in, and is posted a contaminated area by a conspicuous sign. In case of long-lived contamination, it is not uncommon to mix such materials with concrete prior to burial. At one west coast research laboratory low-level solid wastes of various kinds are mixed with concrete in steel drums and disposed of by dumping in deep waters many miles from shore.

Equipment or construction material which may have value, but has been removed because it is too radioactive to be used with safety or which is too bulky for disposal by burial is usually stored above ground in a fenced-off storage yard, well marked and regularly monitored. In time, after decay of the radioactivity some of this material and equipment may be safe for reuse or for sale through commercial channels.

Liquid Wastes

At the present time the Commission has in storage large quantities of highly radioactive uranium-bearing and fission-product wastes resulting from the separation and decontamination of plutonium. Storage is in buried tanks of steel and concrete construction. This method of disposal is very expensive indeed. Extensive and promising research work has been carried out on ways and means of reclaiming the available uranium in certain of these wastes and other valuable material in the decontamination wastes.

At the Hanford Works the storage for years of the decontaminated wastes has permitted decay of radioactivity to a point where disposal to the ground by cribbing has been practical as a temporary measure. It has been observed that a large amount of the radioactive wastes which were cribbed have become attached to the soil and have become fixed in place in the vicinity of the crib. The effect of discharge of these wastes is ascertained by monitoring regularly through wells drilled around and under the cribs. Observation wells on a defined pattern around and at varying

distances from the cribs permit studies to be made of the geology in the general area and an evaluation of the direction and rate of movement of the ground water from the contaminated zones.

On leaving the Hanford reactors the cooling water contains many high-level but short-lived radioisotopes. After several hours of storage in open reinforced concrete retention basins they lose their activity. The effluent from the basin is monitored regularly. The treatment of the water prior to use in the pile is such that on release from the basin about 80 per cent of the radioactivity present in the water is due to Na^{23}. The dilution of the effluent water in the Columbia River is very great. After much study of the problem the health physicists at the Hanford Works have expressed the opinion that there is no radioactive contamination of the river of public health significance to existing downstream users of the river as a source of water supply.

As in other open reservoirs, in areas of prolonged sunshine, there is a prolific growth of algae in these retention basins. There is evidence that the algae in the basins and in the river are not adversely affected by this radioactivity; also that they pick up and concentrate radioactivity in their systems. Similarly biologic growths in the river and its bed below the cooling water outlets are unaffected by and actually pick up considerable amounts of radioactivity. The effect of this concentration on fish life and on other organisms in the biological chain is under investigation.

At Oak Ridge uranium bearing wastes have been stored for years in underground tanks, the metal being precipitated by special chemicals. Other highly radioactive but nonuranium bearing wastes from the production of isotopes, from the various laboratories and from solutions brought in from other operating areas are also stored in underground tanks. These storage tanks also receive the decanted supernatant from the tanks storing the uranium-bearing wastes. After decay to a suitable level the wastes are released to an open retention basin in which further decay takes place. After monitoring these low-level wastes discharge to White Oak Creek and thence to the Clinch, a tributary of the Tennessee River. As at Hanford, algae grow prolifically in these basins.

Operations are directed to limit the activity of discharge to the Clinch River to 25 curies per week or not in excess of 1 microcurie per liter. These levels are considered to be safe. In September 1949, equipment was installed at the ORNL to evaporate the high-level radioactive wastes stored in underground tanks. This test facility has a demonstrated decontamination factor that has made it unnecessary to install additional waste storage tanks.

At Los Alamos liquid wastes from production and research areas where radioactive materials are handled and from a laundry where clothing of production and laboratory workers is decontaminated are discharged into the deep canyons. In the production area and the laundry the wastes pass through surface filter beds constructed some years ago using native soils of tufa. As a result of clogging, the efficiency of these beds which was once high has deteriorated. In flow down the side of the canyon wall and in the bed of the canyon adsorption of radioactivity in the soil is reported to be high.

The Geological Survey is now cooperating by making a study of the geology of these canyons in an effort to trace the effect, if any, on ground water of these disposal practices. The canyons in the vicinity of these disposal areas are fenced in and posted as contaminated areas. They are monitored regularly. The Public Health Service is cooperating with the AEC and the University of California in research to develop better methods of treating all of these waters prior to disposal.

At the newer national laboratories at Argonne (near Chicago) and Brookhaven (on Long Island) liquid wastes are to be stored in underground tanks pending further research as to more suitable and economical methods of disposal. At the Knolls Atomic Power Laboratory near Schenectady, evaporation of wastes is being carried out effectively.

Gaseous Wastes

A very substantial amount of progress has been made in the control and removal of contamination from gaseous effluents resulting from atomic energy operations.

Originally it was thought that by installation of ventilation systems within the buildings and high stacks for release of effluents from the chemical separations operations at production areas dilution in the atmosphere would be sufficient to prevent radioactive contamination of the working areas and vicinity from becoming a serious health factor. It was expected that the principal contaminant would be radioiodine (I^{131}) having a half-life of 8.0 days. Experience and meteorological research have shown, however, that during periods of unfavorable atmospheric conditions dissolver operations could not be carried on without contamination in excess of that which was considered safe at and in the vicinity of the working areas near the stacks. In the light of these findings when meteorological conditions are unfavorable for atmospheric dilution, dissolving operations are suspended. Early in the operations, field monitoring indicated that deposition of radioactive iodine on vegetation was taking place. The later finding of radioactive particulate matter on the ground in the vicinity of the stacks served to stimulate special interest in the problem and ways and means of resolving it. The record of appraising this situation at the Hanford Works and of subsequently developing control measures is an outstanding one. Effective ways of reducing this contamination include the installation of fibrous filters in the exhaust ventilation system of each cell, scrubbing the dissolver off-gases, and filtering the final effluent through sand beds prior to discharge to the stack. The Commission recognized the importance of this stack gas problem and in May 1948, appointed a special working group consisting of seven outside experts in atmospheric pollution from industry and universities to advise it and to assist the technical staff in the various areas in their problems. This group has been instrumental in suggesting and in carrying out research programs which are discussed elsewhere in this paper.

The Chemical Warfare Service has been most helpful in supplying the Commission and its contractors with a fibrous filter material it had developed and in manufacturing filter assemblies in various sizes to meet

specifications for use in production areas and laboratories. Representatives of manufacturers of air cleaning equipment and outside research laboratories have also been most helpful.

It is most important that air used to ventilate areas where radioactive materials are being processed or used to cool reactors be as free of particulate matter as possible. Pretreatment such as filtration is most desirable. Contaminants evolving from chemical processing should be removed as near as possible to their point of origin and not be permitted to enter larger ventilating streams from which their removal may be quite expensive.

In an air-cooled reactor there is always the possibility of a leak of irradiated material from the fuel container. About a year ago provision was made at the Oak Ridge National Laboratory for the installation of special fibrous diaphragm filters in the effluent line between the reactor and the stack. The results obtained from use of these filters have been highly gratifying with removal efficiencies in excess of 99 per cent.

Since May 1948, the Commission has insisted that all radioactive contaminants be removed from gaseous effluents. Most of the installations are meeting this provision by the installation of the Chemical Warfare type fibrous filter in the stream of the ventilation systems. In some cases other decontamination facilities such as electrostatic precipitators or glass wool roughing filters are installed in advance of the terminal filters. The installation of these facilities in new and existing plants has cost a large sum of money, but it is a justifiable expense in the interest of workers and the public. In new laboratories where work involving materials of high, intermediate, or low levels of radioactivity is used, as well as nonradioactive materials, it is customary to segregate the working areas. Space ventilation is maintained at various pressures so that leakage is always from a low-level area to a higher one. Monitoring of the ventilating air is carried out continuously. New hoods are designed to give uniform flow of air across the working area under all conditions; and each hood has its own filters in addition to those in the main influent and effluent systems. At one of the laboratories all work on radioactive materials is carried out in dry boxes rather than in special hoods. The effluent air from each box is filtered.

WASTES RESULTING FROM RADIOISOTOPE DISTRIBUTION PROGRAM

The disposal of waste resulting from the use of radioactive isotopes is an important issue which confronts the industry. The quantity of radioactive material involved is insignificant in comparison with that in the waste products at production plants. The distribution of the isotopes is, however, widespread. They may be used by a great number of people not under the immediate and continuing supervision of health physics monitors. Nearly 10,000 shipments of isotopes have been made to date for use in research in medicine, biology, bacteriology, chemistry, pharmacology, meteorology, metallurgy, and a variety of industrial operations. Shipments

have been made to all states of the union and to many foreign countries. To date the principal interest has been in isotopes having relatively short half-lives such as P^{32} (14.3 days), Na^{24} (14.8 hr), I^{131} (8.0 days), and Co^{60} (5.3 years). However, there has been some use of C^{14} with a half-life of 5,000 years.

It is clear that personnel working with these isotopes must be familiar with the hazards involved in their use and in their disposal. If radioactive wastes were to be disposed of by flushing into the normal plumbing facilities at a laboratory or hospital this practice might create a series of problems. Pipes, traps, and other units in the plumbing system could become contaminated and this could result in an overexposure to radioactivity by maintenance personnel. As a liquid contaminant of institutional plumbing system radioactivity becomes a new hazard to be considered in the cross connecting of water and sewer piping. Then there is the problem of the effect of radioactivity in the public sewers system and the sewage treatment methods used, some of which depend on sensitive biochemical processes. It is known that the slimes normally found in sewer pipes and drains will adsorb and concentrate radioactivity from liquid wastes flowing through the pipes.

Public health and public works officials are much concerned over the effect of this new contaminant and research projects are under way to assist in getting answers to some of the questions they have raised.

The AEC Isotope Division assures itself of the competence of users of these materials, and through its circular B-6 it has given interim recommendations for the disposal of radioactive wastes by off-commission users. In the case of radioiodine and radiophosphorus it recommends that the daily volume of water flowing from the sewage outlet of the institution to the main sewer be sufficient to dilute these isotopes to 0.5 and 0.1 microcuries per liter respectively; also, that the maximum activity disposed of from any one institution not exceed 200 millicuries per week. In the case of radiophosphorus it recommends that each millicurie be diluted with 10 g of phosphorus as phosphate at the time of each discharge. For disposal by burial in a selected area with 5 ft of earth cover, it recommends dilution with a stable isotope of the same chemical element and in the same form to the extent that 4.15 ergs are dissipated per gram of element per day.

It is clearly recognized that the problems involved in the handling, transportation, use, and disposal of radioisotopes are important and have possibilities of becoming more vexing as the use of these materials becomes more common. A subcommittee on Waste Disposal and Decontamination has been established by the National Committee on Radiation Protection and a report from that committee is in preparation.

RESEARCH AND DEVELOPMENT

Substantial progress has been made in the atomic energy industry in attacking, on all fronts, problems of waste disposal. Research and development work has been carried out under Commission sponsorship by the technical

staffs of contractors at production areas and the research laboratories, by contracts with outside consultants and universities and in cooperation with federal and other public agencies interested and concerned in atomic wastes. Practical methods of reclaiming uranium from stored wastes have been developed and some facilities for carrying out these processes already are under construction. The era of storage of large volumes of high-level wastes at exceedingly high costs is coming to a close.

Early in the growth of the industry research with columns using natural soils at Hanford and Los Alamos showed how effective such media were in adsorbing radioactivity. Later, numerous studies of ion exchange material were made which demonstrated high efficiencies in decontamination of radioactive wastes. These processes were not, however, found to be entirely efficient in removing certain long-lived fission products. Then also, there was the problem of handling final disposal of the exchange material after regeneration.

During the past year much interest has developed in evaporation as a means of reducing volume and decontaminating liquid wastes. Decontamination factors with substantial volume reduction have been demonstrated as practical. At Los Alamos biochemical methods (using activated sludge) of decontaminating low-level radioactive solutions of plutonium have been studied on a limited basis in a cooperative program with the University of California and the Public Health Service. Results show that more than 95 per cent removal can be effected in a single stage of treatment. One or more additional stages would, it is believed, give almost complete removal. Using aluminum or iron compounds as coagulants followed by plain settling and filtration through sand, efficiencies of decontamination in excess of 99 per cent are indicated. Pretreatment for adjustment of pH to above 10.0 is indicated if the wastes contain such dispersing agents as citrates or phosphates. The reduction in volume and ultimate disposal of the resulting denatured sludges has yet to be worked out. Effective and economical methods of recovery of radioactive materials by extraction processes are being sought.

Intensive research is in progress to develop an incinerator which will be efficient and effective in reducing combustible solid material or dried sludges to low volume ash and in decontaminating the products of combustion. Contracts for such research and development have been placed with outside experts in combustion problems. It is proposed in some cases that the ash be mixed with a dense concrete for ultimate disposal by burial or at sea. The Bureau of Mines through its combustion Research Laboratory has been asked to appraise this problem in the various areas and to give special attention to the development of a small incinerator for the disposal of radioactive solid wastes at research institutions using radioactive isotopes.

It has been clearly demonstrated that in the decontamination of radioactive gaseous effluents further research must be carried out to determine the character and distribution of particle sizes in various wastes and their types of radioactivity. Contracts have been placed for basic research of the properties of aerosols of special interest to the industry in relation to its gaseous wastes, their properties and behavior.

The Army Chemical Corps filter medium has been studied for a variety of uses in the industry. The Corps and outside consultants have developed assemblies of various sizes for use of this paper in laboratories and production plants. A substitute filter paper using more readily available fibrous material has been developed and its properties are being investigated. It is to be expected that in the near future assembly units for general use within and outside the industry will be manufactured by commercial firms. Substitute filter media such as glass fibers have been studied and offer much promise especially as prefilters and where high temperatures are encountered.

Because air cleaning equipment used in dealing with radioactive wastes may ultimately become highly contaminated with radioactive material, it is important that special consideration be given in design to the important feature of accessibility for maintenance without exposure of employees. Research is planned which will give special consideration to the performance of standard air cleaning equipment under the conditions which prevail in the atomic energy industry with the objective of working with manufacturers in making such changes in assembly as may be needed for this unique service. Included in such studies will be such equipment as cyclones, bag, diaphragm and deep bed filters, scrubbers, sonic agglomerators, and electrostatic precipitators.

The Sanitary Engineering Departments of The Johns Hopkins and New York universities have contracts with AEC for the study of the effect of radioactive isotopes on the biologic slimes commonly found in sewers and of significance in sewage treatment. The Massachusetts Institute of Technology, Department of Sanitary Engineering has a contract to investigate the effectiveness of standard methods of water purification in removing radioactivity from water. A similar research contract is being developed for work at the Oak Ridge National Laboratory in cooperation with the Department of Defense and the Public Health Service.

The Geological Survey has for over a year carried out research at the Hanford Works in cooperation with the AEC and the General Electric Company to determine the effect of the disposal of radioactive wastes by cribbing on the ground waters in the area. That agency is conducting similar studies in the canyons at Los Alamos and is cooperating with the Department of Geology, University of Tennessee in an investigation of the extent of underground pollution, if any, from the waste storage tanks and waste disposal basins, at the Oak Ridge National Laboratory.

The University of Washington is conducting extensive research on the effect of discharge of radioactive cooling water from the reactors at the Hanford Works on the algae, diatoms, and other biological growth in waters of the Columbia River and on the river bed.

The Weather Bureau has conducted special surveys of meteorologic conditions at and in the vicinity of production areas and national laboratories as related to the spread of radioactive contaminants from stacks and hoods should unusual conditions develop in the release and control of gaseous effluents from industry operations.

CONCLUSIONS

The problems which arise in the disposal wastes of this new industry require careful appraisal within and outside the industry from the standpoint of personal and public health, economics of treatment and reclamation of product where practical. Within the industry they are being given a great deal of consideration and much money has been and is being spent providing facilities for handling these wastes properly; and also for developing facts on which to develop better methods of resolving the waste disposal complex. Outside the areas of the industry's operation these problems are of special interest and concern to public officials responsible for the quality and safety of surface and ground water resources and the purity of the air we breathe and the food we eat. Although disposal of wastes from this new industry is but one of the many of its fascinating facets of activity, it is an important one and one which holds out a challenge to the chemical engineer, the sanitary engineer, the biochemist, and the biologist. Their respective interests and opportunities are manifold and through good teamwork current and future problems of waste disposal can be partly or completely solved. Indeed, the future growth of this new industry from the developmental stage to that of applied use of its products may well hinge on its ability to find increasingly effective and reasonably economical methods of disposal of its hazardous waste products.

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